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Five Describing Factors of Dyslexia

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Abstract

Two subtypes of dyslexia (phonological, visual) have been under debate in various studies. However, the number of symptoms of dyslexia described in the literature exceeds the number of subtypes, and underlying relations remain unclear. We investigated underlying cognitive features of dyslexia with exploratory and confirmatory factor analyses. A sample of 446 students (63 with dyslexia) completed a large test battery and a large questionnaire. Five factors were found in both the test battery and the questionnaire. These 10 factors loaded on 5 latent factors (spelling, phonology, short-term memory, rhyme/confusion, and whole-word processing/complexity), which explained 60% of total variance. Three analyses supported the validity of these factors. A confirmatory factor analysis fit with a solution of five factors (RMSEA = .03). Those with dyslexia differed from those without dyslexia on all factors. A combination of five factors provided reliable predictions of dyslexia and nondyslexia (accuracy >90%). We also looked for factorial deficits on an individual level to construct subtypes of dyslexia, but found varying profiles. We concluded that a multiple cognitive deficit model of dyslexia is supported, whereas the existence of subtypes remains unclear. We discussed the results in relation to advanced compensation strategies of students, measures of intelligence, and various correlations within groups of those with and without dyslexia.

Keywords

dyslexia, methodological issues, cognitive strategies

One of the hottest topics in studies of dyslexia is the existence of subtypes, which was suggested 20 years ago by Castles and Coltheart (1993). The main question is whether dyslexia should be considered as one disorder with one cause but with different behavioral outcomes, or as a collection of different disorders with some similar symptoms. This debate is complicated by the existence of an overwhelming quantity of reported symptoms, hypotheses, and theories, and by the various ways researchers have tried to incorporate all of these findings into causal explanations.

In the literature, we found many symptoms well supported by evidence: impairments of reading (Marinus & De Jong, 2010) and spelling (McCarthy, Hogan, & Catts, 2012), reversal errors (Lachmann & Geyer, 2003), impaired phonological processing (Blomert & Willems, 2010; Vaessen & Blomert, 2010; Ziegler et al., 2010; Ziegler & Goswami, 2006), auditory processing (Schulte-Körne & Bruder, 2010), automatization (Nicolson, Fawcett, Brookes, & Needle, 2010), short-term memory (De Jong, 1998; Savage, Lavers, & Pillay, 2007), rapid naming (De Jong & Van der Leij, 1999; Holopainen, 2002), morphological awareness (Siegel, 2008), visual processing (Bosse, Tainturier, & Valdois, 2007), and attention (Bosse, Tainturier, & Valdois, 2009; Facoetti, Corradi, Ruffino, Gori, & Zorzi, 2010; Facoetti et al., 2009). How should subtypes of dyslexia be related to this overwhelming quantity of symptoms and theories? This question was discussed by Ramus and Ahissar (2012), who stated, "The abundance and diversity of these new theories partly stem from the fact that the large body of data on cognitive deficits in dyslexia fails to fit into a single coherent theoretical framework" (p.105). Nevertheless, these authors found that two subtypes can be distinguished in the literature: a majority subtype characterized by a phonological deficit and one or several minority subtypes characterized by a visual deficit, whereas additional subtypes of phonological and visual dyslexia might emerge from the consideration of underlying etiologies. However, no studies have provided evidence for distinct, reliable cognitive (or biological) profiles associated with each subtype. Nevertheless, both phonological and visual/attentional impairments have been

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proposed to represent the core deficit of dyslexia (for a discussion, see Vidyasagar & Pammer, 2010).

One thing that researchers agree on is that the most common symptoms of dyslexia are related to language difficulties, especially reading and spelling. For instance, a general definition of the World Health Organization (2008) states that dyslexia is a specific reading disorder characterized by a specific and significant impairment in the development of reading skills that is not solely accounted for by mental age, visual acuity problems, or inadequate schooling. Clearly, any subjective view of the causal nature of dyslexia is left out of this definition. However, because reading and spelling abilities cannot have an evolutionary basis by themselves, they must emerge from cognitive abilities that are required for reading and spelling. The discussion about which and how many cognitive abilities these might be (phonological, visual, or any other) is important for reliable diagnoses of dyslexia. Diagnoses based on reading and spelling abilities and subjective theoretical preferences of specialists might result in false positives and false negatives. Moreover, the influence of compensation strategies can then not objectively be determined.

The complex relation between reading deficits and cognitive deficits was underlined in a study by Menghini et al. (2010). These researchers investigated the idea that dyslexia might be accompanied by quite a large number of independent deficits, as proposed by the multiple cognitive deficit model of dyslexia (Pennington, 2006). They conducted a general linear model analysis, taking into account that various tasks require multiple cognitive abilities that are not limited to a single cognitive domain. In a sample of children between 8 and 17 years of age, these researchers found that in a four-step hierarchical regression analysis about half of the variance in two reading efficiency tests could be explained by cognitive deficits, such as phonological, visuospatial, attentional, and executive impairments.

In a study by Le Jan et al. (2011), an attempt was made to refine the diagnosis of dyslexia with a multivariate predictive model based on cognitive deficits only and not on deficits of reading and spelling. Using various exploratory analyses, these researchers found that eight variables from four cognitive categories (metaphonological, morphology knowledge, visuoattentional, and audition) classified 94% of children from elementary school correctly. Dyslexia that can be predicted with such a high reliability without a reading and spelling assessment could mean a change of paradigms: dyslexia defined as a combination of cognitive deficits instead of a reading disorder. The predictive model of Le Jan et al. implies that these categories are relatively independent from each other. However, because the number of variables almost exceeded the number of those with dyslexia in this study, exploratory factor analyses were performed within categories and not between categories. Typically, multivariate analyses for investigating how various symptoms of dyslexia are related require large samples, or fewer variables than used in the study by Le Jan et al.

When samples are large enough, the advantage of exploratory analyses is that latent variables can be extracted and interpreted without making theoretical assumptions beforehand. To our knowledge, this has been done only a few times before, on a limited set of tests. For instance, Bosse et al. (2007) conducted a principal components analysis in two different samples of French and English children. Data from three phonological tasks and three visual attention span tasks revealed that a visual attention factor accounted for 35.8% of the variance in the French sample and for 40.6% in the English sample, and that a phonological factor accounted for 27.1% of the variance in the French sample and for 33.9% in the English sample. In addition, the researchers tried to determine whether subtypes of dyslexia could be distinguished. They defined selective deficits of each factor such that children were considered as being impaired on a factor when their factorial score fell below the 10th percentile of the control group factorial coefficient. They found that 15% of the French and 7% of the English with dyslexia had both disorders, 19% of the French and 34.5% of the English with dyslexia a selective phonological deficit, 44% of the French and 34.5% of the English with dyslexia a selective visual deficit, and 22% of the French and 24% of the English with dyslexia no deficit at all.

In another study, Di Filippo and Zoccolotti (2012) conducted a factor analysis on various rapid automatized naming tasks in a sample of Italian children. They found that a naming factor accounted for 61.43% of the variance and that a visual search factor accounted for 14.44% of the variance. The first factor specified two factors: pictorial naming and detailed orthographic analysis. Because the pictorial naming factor included both orthographic and nonorthographic stimuli, the authors argued that naming slowness

> is not specifically related to activation of the orthographic lexicon but refers more generally to the ability to retrieve name codes from the semantic lexicon. Therefore, the pictorial factor seems to require the integration of visually derived and phonological codes. As such, it might be relatively independent from purely visual or phonological processes. (p. 386)

The studies by Bosse et al. and Di Filippo and Zoccolotti revealed that factor analysis is a useful tool for extracting independent cognitive features of dyslexia. However, a few details of these studies need some clarification. The children with dyslexia in these studies were selected based on delayed reading. However, although delayed reading is the main element and the only symptom in the definition of the World Health Organization, some caution is required. The possibility exists that some (highly intelligent) children with dyslexia are able to compensate for impaired reading already at the ages around 11 years, which can result in the exclusion of some with dyslexia from samples. On the other hand, children without dyslexia with delayed reading, caused by something else other than dyslexia (low intelligence or poor schooling), may be included in samples. For example, in the study by Le Jan et al., 5 of 13 poor readers who were never investigated before were predicted to be without dyslexia by the cognitive prediction model. The existence of poor readers without dyslexia might explain why almost a quarter of the children with dyslexia in the study of Bosse et al. did not show phonological or visual deficits. Another explanation for these results could be that these children without deficits in fact have dyslexia, but with symptoms not measured that still resulted in delayed reading.

We concluded that in most studies, cognitive features are investigated in relation to reading deficits, except for the study by Le Jan et al. (2011). In this study, however, an exploratory factor analysis of many symptoms could not be performed due to a relatively small sample. Nevertheless, the finding that dyslexia can be diagnosed on the basis of cognitive variables without assessing reading or spelling deficits highlights that a systematic exploration of cognitive features underlying dyslexia is justified.

The aim of the present study was to investigate how many independent features can be found in a large battery of tests assessing various deficits related to dyslexia. These included both cognitive abilities such as phonology, but also reading and spelling abilities. To ensure that multivariate analyses could reliably be performed, we used a large sample of 446 students. In addition, we investigated whether the same features could be extracted from a large self-report questionnaire. We took four successive steps in the analysis of the data. First, we performed exploratory factor analyses on both the tests and the questionnaire independently as well as a confirmatory analysis on the whole set. Second, we investigated differences in the latent variables between those with dyslexia and those without. Third, we investigated the validity of the factors of dyslexia by analyzing the predictive power of the factors and by investigating relations between factors of dyslexia and factors of intelligence. Fourth, we investigated whether subtypes of dyslexia can be distinguished by analyzing individual profiles based on cognitive features of dyslexia.

Method

Participants and Procedure

We used data from 446 first-year psychology students (17–25 years, 114 males), collected in a previous study (Tamboer, Vorst, & Oort, 2014). This sample consisted of three groups: those with dyslexia (n = 63, 14%), those without (n = 345, 77%), and unknown (n = 38, 9%). All students were raised in the Netherlands, had no serious health problems, and had no history of any serious neurological disorder. The data were collected at the University of Amsterdam. All students were informed about the general nature of the tests and the questionnaires in advance according to a standard protocol. Afterward, the students received a more detailed debriefing. Anonymity was guaranteed by the standard protocol of the University of Amsterdam. All students had up to 3 weeks after their debriefing to request that their test results were not used.

Assessment of Dyslexia

Dyslexia and nondyslexia were assessed with two methods. First, dyslexia and nondyslexia were determined with six sources of biographical information: a formal diagnosis by an educational psychologist, other test results (at school or at an institution), school records of remedial training during school days, family members with dyslexia, and a general self-assessment of dyslexia. Only in the case of high consistency were students identified as being with dyslexia or not. Second, we applied various discriminant and logistic regression analyses on 10 tests and a self-report questionnaire. In this way, all students could be classified as having dyslexia or not. Finally, dyslexia and nondyslexia were determined based on consistency between the two methods. This resulted in a group of 63 students with dyslexia, a group of 345 students without dyslexia, and a relatively small group of 38 students who could not be identified because there was too much inconsistency between the two methods of identification.

An important issue in many studies is selection bias. Different selection procedures across studies can result in exclusion of those with dyslexia in some samples, whereas in other samples of those without dyslexia are falsely included. In the present study, we prevented inclusion of those without dyslexia in the dyslexia sample by requiring consistency between two independent methods of identification. Exclusion of those with dyslexia from the dyslexia sample was prevented by the discriminant and logistic regression analyses that classify students without making assumptions about which symptoms of dyslexia are most important. For instance, some students from the sample with dyslexia had many biographical indications of dyslexia, but only no formal diagnosis of dyslexia. The regression analyses prevented those with real dyslexia without a formal diagnosis to be excluded from the dyslexia sample. Nevertheless, in the case of too much inconsistency, students were classified into the group of not identified.

In addition, we used the regression function that has acquired the best prediction of dyslexia as a measure of severity of dyslexia. Figure 1 shows the distribution of this score. This standardized score is clearly not normally distributed, but consisted of two separate distributions with all of those with dyslexia falling within the smallest group and

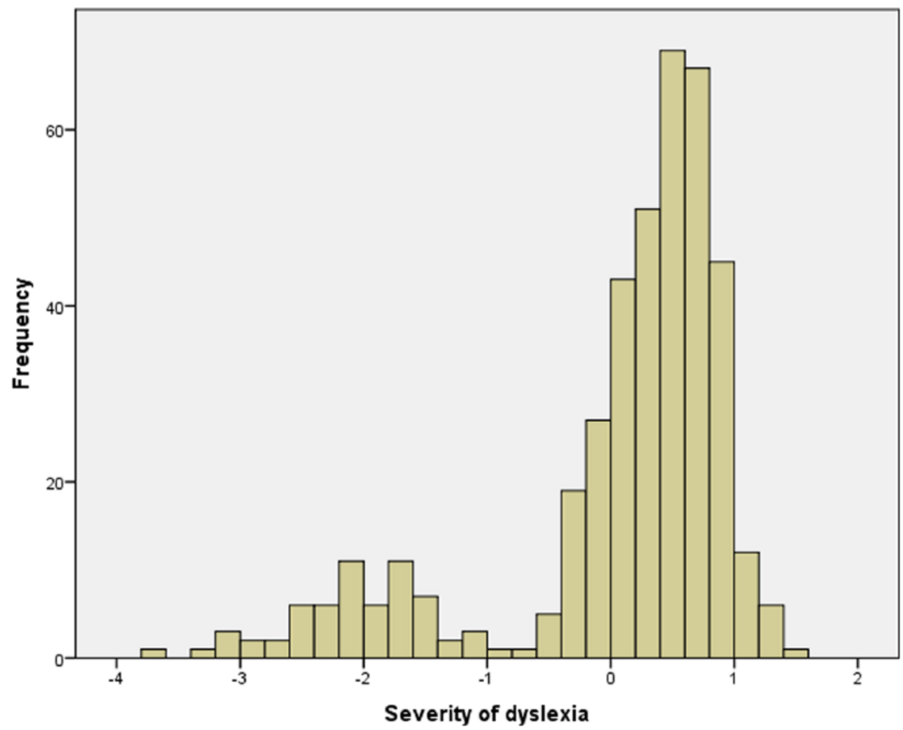

Figure 1. Frequency distribution of severity of dyslexia z regression score.
Note. N = 446. A low score represents more severe dyslexia.

Table 1. Sample Characteristics of Students With and Without Dyslexia: Gender, Age, and Handedness.

Sample characteristics	With dyslexia (*n* = 63)	Without dyslexia (*n* = 345)
Age (years)	20.1 (1.7)	19.7 (1.5)
Age (months)	241 (21)	236 (19)
Gender (male; *n*, %)	18 (28.6)	83 (24.1)
Gender (female; *n*, %)	45 (71.4)	262 (75.9)
Handedness (right; *n*, %)	53 (84.1)	289 (83.8)
Handedness (left; *n*, %)	4 (6.3)	39 (11.3)
Handedness (ambidextrous; *n*, %)	4 (6.3)	15 (4.3)
Handedness (missing data; *n*, %)	2 (3.2)	2 (0.6)
Severity of dyslexia (z-score)	−2.01 (0.67)	0.44 (0.40)

Note. Values are means and standard deviations, unless otherwise noted.

all of those without dyslexia falling within the largest group. The means of both groups differed (SD = 2.45) on this standardized score. The groups of those with and without dyslexia did not differ in age, ratio of men to women, or percentage of right-handedness (see Table 1).

Tasks

We selected nine tests that are related to cognitive aspects of language processing and a short-term memory test. We did not categorize these tests because we assumed that some tests may require various cognitive abilities. Nevertheless, we tried to incorporate various difficulties of those with dyslexia in these tests, such as phonological, visual, attentional, auditory, and spelling difficulties. Furthermore, we incorporated a large self-report questionnaire, assessing the same difficulties, because we found in our previous study (Tamboer et al., 2014) that combinations of self-report questions can reliably predict dyslexia. Further support for the predictive value of a self-report can be found in a study by Snowling, Dawes, Nash, and Hulme (2012). In this study, a factor analysis showed two factors related to dyslexia underlying a 15-item questionnaire: reading and word finding.

Self-report questions. The *Communication Questionnaire* (Kramer & Vorst, 2007) aims to acquire information about specific language difficulties. The term *dyslexia* is not mentioned in this questionnaire. The questionnaire was designed according to a 7 × 5 × 4 facet design. There are seven subscales representing different aspects of language, each consisting of 20 statements with seven response categories. Here, we give an example for each subscale: reading: "Sometimes I skip a letter, which results in reading a different word"; writing: "Sometimes I forget to write down a syllable"; speaking: "While speaking, I sometimes exchange similar words"; listening: "I hear a story exactly like someone tells it"; copying: "When I copy out a text, I sometimes exchange letters with similar sounds"; dictating: "I make mistakes in dictation, because I don't hear the correct sounds"; reading aloud: "When reading aloud, I sometimes repeat a part of the text." All statements can also be categorized into five subscales representing sounds, letters, words, sentences, and text. A leading thought during the creation of statements was that four typical mistakes might distinguish those with dyslexia from others: skipping (forgetting), adding, changing, and exchanging.

Short-Term Memory. The *Short-Term Memory Test*—designed for our previous study—aims to measure the capacity of short-term memory. We used the concept of digit span: the number of digits a person can retain and recall. There are four subtests: numbers and letters, both forward and backward. And each subtest consists of 24 series: 6 of 4, 6 of 5, 6 of 6, and 6 of 7 items for the subtests numbers and letters forward, and 6 of 3, 6 of 4, 6 of 5, and 6 of 6 items for the subtests numbers and letters backward. The numbers and letters are presented one by one, for 1 second each on a computer screen. The participants have to retype these numbers and letters after the last one of a series has been presented. About half of all series consist of some typical difficulties for those with dyslexia, either phonological, visual or both. For example, a typical phonological confusion is between the numbers 7 and 9, which resemble each other phonologically in Dutch (zeven/negen). Typical visual confusions are between the numbers 6 and 9 and the letters [m] and [w]. The letters [p], [d], and [b] resemble each other phonologically as well as visually.

Cognitive language tests

1. Dutch dictation consists of 10 sentences in the Dutch language (maximum score 10 × 4 = 40). Each sentence was read aloud and could be heard through headphones. The whole sentence had to be typed into the computer. Each sentence consisted of a few words that are vulnerable to spelling errors.
2. English dictation consists of 10 sentences in the English language (maximum score 10 × 2 = 20). Each sentence was read aloud and could be heard through headphones. At the same time, this sentence, except two words, could be read on the computer screen. These words had to be retyped into the computer. Although Dutch students are familiar with the English language, some English words are well known for their vulnerability to spelling errors for Dutch people. The two words had to be typed into the computer.
3. Missing letters consists of 10 sentences in the Dutch language (maximum score 10 × 2 = 20). Each sentence was read aloud and could be heard through headphones. For each sentence two words were repeated, while these words were shown on the computer screen with a few letters left out of both words. The missing letters had to be typed into the computer.
4. Pseudowords consists of 30 pseudowords (maximum score 30), which are nonwords that sound like real words. Each pseudoword was read aloud and could be heard through headphones. At the same time this pseudoword was presented on the computer screen. It had to be decided whether the visually presented pseudoword was spelled correctly, which was the case for half of all pseudowords. Usually pseudowords are administered the other way around, with participants reading the words aloud themselves. The reason for changing this was that it would be practically impossible to get all students in private sessions for this test.
5. Sound deletion consists of 20 difficult Dutch words (maximum score 20). Each word was read aloud and could be heard through headphones. Some of these words were pronounced correctly and some words incorrectly by leaving out or adding one letter. On the computer screen, each word was presented three times, each time with a slightly different spelling with one of them being spelled correctly according to what was pronounced. Participants had to decide which of the visually presented words was heard through the headphones. For example, the existing word "fietsenstalling"—which means bicycle shed—was read out as "fiestenstalling." The possible answers were "fietsentalling," "fiestensalling," and "fiestenstalling."
6. Spoonerisms consists of 20 words (maximum score 20). A spoonerism is a word that consists of two existing smaller words and that still consists of two small existing words when the first letters of both small words are exchanged. Each word was read aloud and could be heard through headphones. For example, the word "kolen-schop" had to be altered into "scholen-kop" and typed into the computer.
7. Incorrect spelling consists of 40 Dutch words (maximum score 40). All words were presented on a computer screen for 50 ms each. Half of the

presented words were spelled correctly and half were spelled incorrectly. The participants had to decide whether the words were spelled correctly or not.

8. Dutch–English rhyme words consists of 40 Dutch–English word pairs (maximum score 40), presented on the computer screen with the Dutch words on the right. For half of the word pairs, the nouns of the Dutch and the English word resembled each other visually but not aurally. For the other half of the word pairs, the nouns of the Dutch and the English word resembled each other aurally. The participants had to decide whether the two words of a pair rhymed or not.
9. Letter order requires the ability to read words as a whole and consisted of 20 Dutch sentences (maximum score 20 × 2 = 40; time limit of 5 min). Theoretical hypotheses about reading words as a whole are described in the dual route model of reading (for an extended description, see De Groot, Dannenburg, & Van Hell, 1994). The idea for this test is based on a well-known text:

> Aoccdrnig to rscheearch at Cmabrigde uinervtisy, it deosn't mttaer waht oredr the ltteers in a wrod are, the olny iprmoetnt tihng is taht the frist and lsat ltteres are at the rghit pclae. The rset can be a tatol mses and you can sitll raed it wouthit a porbelm. Tihs is bcuseae we do not raed ervey lteter by it slef but the wrod as a wlohe.

We created Dutch sentences based on the same principle; the order of letters in the words was changed, apart from the first and last letters. The sentences became more difficult toward the end of the test. The sentences had to be typed in with all words correctly spelled. For example, the word "Aoccdrnig" should be typed as "According."

Intelligence tests. Six cognitive tests were based on Guilford's structure of intellect model: (a) vocabulary (cognition of semantic units: knowing and understanding words and concepts), (b) verbal analogies (cognition of meaningful verbal relations), (c) conclusions (cognition of meaningful symbolic relations, or the ability to understand and structure difficult situations and the evaluation of semantic implications), (d) numeric progressions (cognition of symbolic systems in progressions of numbers), (e) speed of calculation (the ability to assess simple symbolic rules), and (f) hidden figures (spatial intelligence). For general (nonverbal) intelligence we used the *Advanced Progressive Matrices Set 2* (Raven, Court, & Raven, 1979).

Analyses

To find latent variables related to dyslexia, we carried out various principal components analyses (PCAs) on the nine specific language tests, the four subscales of the *Short-Term Memory Test*, and the specific self-report questions of the *Communication Questionnaire*. A confirmatory factor analysis was carried out in LISREL. All analyses were carried out with the whole sample of 446 students. This means that the issue of selection bias is not relevant for these analyses.

The validity of the factors of dyslexia was further investigated in two ways. First, group differences between students with (n = 63) and without dyslexia (n = 345) on factor scores were determined with t tests. Second, the predictive power of the five factors was analyzed with discriminant analysis and logistic regression analysis.

The existence of subtypes of dyslexia was investigated by assessing the nature and number of specific factorial deficits on an individual level. Factorial deficits were determined with scores lower than the 10th percentile for the group of those without dyslexia.

Possible relations between dyslexia and intelligence were investigated with correlational analyses of factors of dyslexia and factors of intelligence. These analyses were carried out for the groups of students with and without dyslexia separately.

Results

The aim was to extract factors of dyslexia from a large data set with exploratory factor analysis. We used the data from the *Communication Questionnaire*, nine specific language tests, and four subscales of the *Short-Term Memory Test*. Table 2 shows all correlations between these scores, with most of them significant at the .01 level. Most correlations are relatively low, except those between the subscales of the *Short-Term Memory Test* and between the subscales of the questionnaire, with the latter ones all greater than .60. These high correlations are problematic when performing factor analysis, because the monotrait–heteromethod correlations should be higher than the heterotrait–monomethod correlations—which appear to be the other way around in this study. Indeed, a PCA based on these scores resulted in only two factors, with all tests loading on one factor and all subscales of the questionnaire loading on the other factor. The next step and successful method was performing factor analyses for the tests and subscales of the questionnaire separately, and then on standardized sum scores of the tests and the questionnaire together.

PCA of the Questionnaire

A plausible explanation for the high correlations between the subscales of the questionnaire is that various latent variables are balanced over the subscales as a result of the 7 × 5 × 4 facet design. To acquire better insight into the nature of the items regarding these three dimensions, we conducted PCAs

Table 2. Correlations Between Sum Scores of 9 Language Tests, 4 Short-Term Memory Tests, and 7 Questionnaires (N = 446).

Test/questionnaire	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Dutch dictation	—																			
2. English dictation	.40	—																		
3. Missing letters	.48	.29	—																	
4. Pseudowords	.27	.15	.24	—																
5. Sound deletion	.09	.08	.12	.26	—															
6. Spoonerisms	.19	.16	.20	.17	.04	—														
7. Incorrect spelling	.44	.37	.39	.13	.02	.19	—													
8. Dutch–English rhyme words	.25	.23	.22	.21	.06	.19	.32	—												
9. Letter order	.22	.19	.18	.19	.06	.13	.21	.19	—											
10. Short-term memory (STM) numbers forward	.25	.23	.24	.24	.17	.15	.27	.29	.21	—										
11. STM numbers backward	.27	.21	.26	.24	.10	.15	.23	.30	.25	**.61**	—									
12. STM letters forward	.28	.30	.26	.22	.17	.17	.26	.30	.20	**.62**	**.53**	—								
13. STM letters backward	.21	.28	.24	.20	.12	.19	.21	.29	.16	**.53**	**.65**	**.65**	—							
14. Questionnaire reading	.24	.23	.29	.12	.08	.14	.26	.30	.18	.29	.24	.31	.23	—						
15. Questionnaire writing	.32	.27	.31	.21	.08	.18	.29	.32	.18	.34	.30	.35	.27	.77	—					
16. Questionnaire speaking	.19	.14	.19	.10	.05	.12	.20	.15	.10	.24	.23	.29	.19	**.66**	**.71**	—				
17. Questionnaire listening	.10	.10	.12	.13	.07	.15	.13	.16	.08	.22	.19	.27	.22	**.60**	**.66**	**.72**	—			
18. Questionnaire copying	.21	.20	.24	.13	.06	.13	.26	.24	.15	.31	.27	.34	.25	**.68**	**.78**	**.68**	**.66**	—		
19. Questionnaire dictating	.29	.26	.29	.19	.05	.14	.30	.27	.09	.31	.26	.32	.24	**.69**	**.82**	**.72**	**.70**	**.83**	—	
20. Questionnaire reading aloud	.20	.23	.22	.16	.02	.13	.25	.24	.13	.30	.27	.33	.26	**.73**	**.77**	**.76**	**.68**	**.80**	**.80**	—

Note. Bold text indicates high correlations.

Table 3. Principal Components Analyses of Subscales of the Communication Questionnaire (*N* = 446).

Subscale	*n* items	*n* factors	Factors
Reading	20	2	Confusion, complexity
Writing	20	3	Confusion, complexity, spelling
Speaking	20	3	Confusion, complexity, phonology
Listening	20	2	Confusion, phonology
Copying	20	3	Confusion, complexity, short-term memory
Dictation	20	3	Confusion, complexity, spelling
Reading aloud	20	2	Confusion, complexity

on the 20 items for each of the seven original subscales separately. For all subscales, this resulted in two or three interpretable factors with eigenvalues greater than 1 (all together 17 factors). Next, we determined for each factor the most common feature of the items with common high factor loadings. We found that many of the 17 factors represented the same latent variable. For example, one latent variable—confusion—was represented as a factor for each subscale. Altogether, five different latent variables could be distinguished: spelling, phonology, short-term memory, confusion, and complexity. The first three of these are not surprising, but confusion and complexity need some clarification. Confusion represented difficulties of skipping (forgetting), adding, changing, and exchanging letters, words, or sentences. Complexity represented difficulties of processing complex words or complex sentences. An overview of these results is presented in Table 3. In the next step, we considered the five latent variables that were found in the seven-factor solutions as five scales, and added up single items according to these scales. This resulted in five sum scores. To be able to compare these with sum scores from the tests, we transformed these sum scores to standardized factor scores by requesting all factors in a PCA. The rotated components matrix is shown in Table 4. The factor scores were assigned names according to the sum scores with the highest factor loading.

PCA of the Tests

A PCA of the nine specific language tests and four subscales of short-term memory resulted in three factors, together explaining only 52% of all variance: spelling, phonology, and short-term memory. The rotated components matrix is shown in Table 5. The spelling factor represented high factor loadings (>0.63) for all tests that are related to spelling disabilities (Dutch dictation, English dictation, missing letters, and incorrect spelling). The short-term memory factor represented high factor loadings (>0.78) for the four subscales of short-term memory. The phonology factor represented high factor loadings for sound deletion (0.81) and pseudowords (0.69). The spoonerisms and letter order tests both had only moderate factor loadings (0.37) on spelling. The test Dutch–English rhyme words had only moderate factor loadings on short-term memory (0.34) and spelling (0.43), which makes the interpretation of this test difficult. However as expected, these are tests that require more than one cognitive ability related to dyslexia.

The finding of the spelling, phonology, and short-term memory factors was consistent with our expectation based on the results of the questionnaire. Unexpectedly we did not find more factors. However, the expectation that more than three latent trait variables might exist is justified for three reasons. First, the three factors from the analysis only explain half of all variance. Second, three tests (spoonerisms, letter order, and Dutch–English rhyme words) are only weakly explained by these factors. Third, inspection of the scree plot revealed that four other latent variables could be distinguished with eigenvalues between 0.7 and 0.9. A possibility is to request more components from the PCA, but the number of extra requested factors would depend on purely subjective decisions. Another possibility is to create five sum scores and test the hypothesis that five latent trait variables can be distinguished according to the same trait variables acquired from the questionnaire. Thus, we created three sum scores by adding the sum scores of the tests with high factor loadings on the three factors from the analysis: spelling (Dutch dictation + English dictation + missing letters + incorrect spelling), phonology (sound deletion + pseudowords), and short-term memory (all four subscales). A fourth factor was acquired by adding the sum scores of spoonerisms and letter order and was named whole-word processing. We used these two tests together because both tests partly depend on the processing of a word as a whole instead of letter-by-letter processing and because both tests show highly similar factor loadings on all factors. The fifth sum score was in fact the sum score of the test Dutch–English rhyme words and was named rhyme. To be able to compare these sum scores with sum scores of the questionnaire, we transformed these sum scores to standardized factor scores by requesting all factors in a PCA. The factor scores were assigned with names according to the sum scores with the highest factor loading, which were greater than 0.95 for each factor.

PCA of the Whole Data Set

We determined five standardized sum scores of the *Communication Questionnaire* and five standardized sum scores of the tests, which represented all variance for the whole data set. We conducted a PCA with these sum scores and found five factors with eigenvalues greater than 1, which together explained 60% of all variance. The rotated components matrix is shown in Table 6. For each of the five factors, one high factor loading was found from a test factor and one from a questionnaire factor, all falling between 0.61 and 0.83,

Table 4. Rotated Components Matrix: Five Factors Explaining All Variance of Five Sum Scores of the Communication Questionnaire (N = 446).

Sum score	Factor 1 (phonology)	Factor 2 (spelling)	Factor 3 (confusion)	Factor 4 (short-term memory)	Factor 5 (complexity)
Spelling	0.25	**0.88**	0.24	0.28	0.17
Phonology	**0.85**	0.26	0.30	0.26	0.23
Short-term memory	0.28	0.33	0.30	**0.83**	0.20
Confusion	0.31	0.26	**0.84**	0.29	0.21
Complexity	0.49	0.32	0.38	0.33	**0.64**

Note. Extraction method: principal components analysis. Rotation method: Varimax with Kaiser normalization. Rotation converged in six iterations. Bold text indicates high factor loadings.

Table 5. Rotated Components Matrix: Three Factors Explaining 52% of the Variance of 13 Tests (N = 446).

Test	Factor 1 (short-term memory)	Factor 2 (spelling)	Factor 3 (phonology)
Dutch dictation	0.08	**0.76**	0.11
English dictation	0.15	**0.63**	−0.01
Missing letters	0.11	**0.67**	0.16
Pseudowords	0.14	0.25	**0.69**
Sound deletion	0.07	−0.03	**0.81**
Spoonerisms	0.11	0.37	0.17
Incorrect spelling	−0.14	**0.74**	−0.14
Dutch–English rhyme words	0.34	0.43	0.09
Letter order	0.18	0.37	0.07
Short-term memory (STM) numbers forward	**0.78**	0.18	0.15
STM numbers backward	**0.81**	0.18	0.04
STM letters forward	**0.79**	0.22	0.11
STM letters backward	**0.84**	0.16	0.04

Note. Extraction method: principal components analysis. Rotation method: Varimax with Kaiser normalization. Rotation converged in six iterations. Bold text indicates high factor loadings.

whereas all other factor loadings were 0.28 or less. As expected, we found a spelling factor (15.7% of the variance explained), a short-term memory factor (12.1% of the variance explained), and a phonology factor (10.8% of the variance explained). We named a fourth factor rhyme/confusion (11.3% of the variance explained), which explains the test factor rhyme and the questionnaire factor confusion. A fifth factor we named whole-word processing/complexity (10.3% of the variance explained), which explains the test factor whole-word processing and the questionnaire factor complexity. This analysis supports the existence of two more factors other than spelling, phonology, and short-term memory.

Validity of Five Dyslexia Factors: Confirmatory Factor Analysis

To find support for the five factors from the exploratory analyses, we conducted a confirmatory analysis in LISREL 8.50. We investigated the hypothesis that the data of the exploratory analysis fitted with a multitrait–multimethod model (MTMM model), which was developed by Campbell and Fiske (1959). We entered the covariance matrix of the five sum scores of the questionnaire and the five sum scores of the tests and distinguished five latent trait variables (the five factors that were found in the exploratory analysis) and two latent method variables (test and self-report). In the suggested model, the variance of each of the 10 sum scores was explained by one trait factor, one method factor, and error variance. Generally, various fit indices are used to quantify the ability of a model to reproduce the observed data. The root mean square error of approximation (RMSEA) is a measure of the error of approximation of the model-implied covariance matrix to the population covariance matrix and should be less than .05. We found an RMSEA of .03 with p = 0.88, which means that the null hypothesis of a close fit cannot be rejected. The root mean square residual (RMR) is a badness-of-fit measure based on the differences between the covariance matrix of the model and the covariance matrix of the data and should be less than .05. We found a RMR of .02, which indicates a good

Table 6. Rotated Components Matrix: Five Factors Explaining 60% of the Variance of 10 Factors of Tests and Questionnaire (*N* = 446).

Factor	Factor 1 (spelling)	Factor 2 (short-term memory)	Factor 3 (rhyme/ confusion)	Factor 4 (phonology)	Factor 5 (whole-word processing/complexity)
Variance explained (%)	15.7	12.1	11.3	10.8	10.3
Questionnaire—spelling	**0.83**	0.01	0.05	0.22	−0.01
Questionnaire—phonology	−0.10	0.28	0.09	**0.61**	0.25
Questionnaire—short-term memory	0.06	**0.71**	−0.13	−0.05	−0.12
Questionnaire—confusion	-0.07	0.21	**0.71**	−0.03	−0.16
Questionnaire—complexity	0.10	−0.03	0.21	−0.18	**0.70**
Test—spelling	**0.82**	0.09	−0.00	−0.13	0.07
Test—phonology	0.15	−0.13	−0.02	**0.77**	−0.15
Test—short-term memory	0.05	**0.72**	0.17	0.11	0.13
Test—rhyme	0.11	−0.17	**0.72**	0.08	0.15
Test—whole-word processing	−0.03	0.03	−0.23	0.20	**0.66**

Note. Extraction method: principal components analysis. Rotation method: Varimax with Kaiser normalization. Rotation converged in six iterations. Bold text indicates high factor loadings.

Table 7. Group Differences on Factors of Dyslexia.

Factors of dyslexia	With dyslexia (*n* = 63)		Without dyslexia (*n* = 345)					Not identified (*n* = 38)	
	M	*SD*	*M*	*SD*	*T*	*p*	Effect size	*M*	*SD*
Spelling	−1.36	1.16	0.31	0.71	15.38	<.0000005	1.79	−0.59	0.84
Phonology	−0.54	1.45	0.10	0.82	4.94	.000001	0.56	−0.01	1.30
Short-term memory	−0.49	1.25	0.15	0.90	4.84	.000002	0.60	−0.53	1.00
Rhyme/confusion	−0.22	1.31	0.12	0.81	2.75	.006198	0.32	−0.70	1.52
Whole-word processing/complexity	−0.58	1.16	0.11	0.94	5.10	.000001	0.66	−0.02	0.91

fit. Other fit indices are based on comparing the fit of a model with the fit of a baseline model: the nonnormed fit index (NNFI) and the comparative fit index (CFI). Both indices should be close to 1. We found an NNFI of .997 and a CFI of .999. Based on these indices, we could accept the hypothesis that five general factors are underlying features that were found in both the test battery and the questionnaire.

Validity of Five Dyslexia Factors: Group Differences

More support for the legitimacy of the factors was found with analyses of group differences. Table 7 shows that those with dyslexia had lower factor scores than those without dyslexia on all five factors of dyslexia. Effect sizes (Cohen's *d*) were calculated by dividing the differences between the means by the mean of the standard deviations. The largest effect size (1.79) was found for the spelling factor. Medium effect sizes were found for the phonology, short-term memory, and whole-word processing/complexity factors. A small effect size was found for the rhyme/confusion factor. We also note that the standard deviations are higher for the group of those with dyslexia as compared to the group of those without dyslexia. In addition, the results of the group of not-identified students are presented. All of their factor scores fell between those of the students with and without dyslexia with some scores closer to those of students with dyslexia and some scores closer to those of students without dyslexia.

Validity of Five Dyslexia Factors: Prediction Analysis

Additional support for the legitimacy of the factors was found with prediction analyses: discriminant analysis (DA) and logistic regression analysis (LRA; stepwise method, cross-validated). The groups of those with and without dyslexia were predicted with all five factors of dyslexia in the regression formula: 92% correctly with DA and 95% correctly with LRA. Table 8 presents an overview of these predictions. As all factors of dyslexia contributed to the

Table 8. Prediction Analyses of Those With and Without Dyslexia With Five Factors of Dyslexia.

Discriminant analysis	Predicted students	With dyslexia	Without dyslexia
Spelling, phonology, short-term memory, whole-word processing/complexity, rhyme/confusion	With dyslexia (*n* = 63)	57	6
92% of cross-validated grouped cases correctly classified.	Without dyslexia (*n* = 345)	27	318

Logistic regression analysis	Predicted students	With dyslexia	Without dyslexia
Spelling, phonology, short-term memory, whole-word processing/complexity, rhyme/confusion	With dyslexia (*n* = 63)	50	13
95% of cross-validated grouped cases correctly classified.	Without dyslexia (*n* = 345)	6	339

Table 9. Factorial Deficits on an Individual Level for Students With Dyslexia, Without With Dyslexia, and Not Identified (Deficit When Lower Score Than 10th Percentile Cutoff Score of Those Without Dyslexia).

Factorial deficit	With dyslexia (*n* = 63)	Without dyslexia (*n* = 345)	Not identified (*n* = 38)
Spelling (%)	77.8	10.0	47.4
Phonology (%)	34.9	10.0	18.4
Short-term memory (%)	38.1	10.0	42.1
Confusion (%)	28.6	10.0	44.7
Exchange/complexity (%)	31.7	10.0	10.5

Table 10. Number of Deficits in the Groups of Students With Dyslexia, Without With Dyslexia, and Not Identified (Deficit When Lower Score Than 10th Percentile Cutoff Score of Those Students Without Dyslexia).

Number of deficits	With dyslexia (*n* = 63)	Without dyslexia (*n* = 345)	Not identified (*n* = 38)
0 deficits (%)	0.0	58.0	5.3
1 deficit (%)	25.4	35.1	42.1
2 deficits (%)	44.4	6.7	39.5
3 deficits (%)	23.8	0.3	10.5
4 deficits (%)	6.3	0.0	2.6
5 deficits (%)	0.0	0.0	0.0

prediction (were entered in the regression equation), the best prediction of dyslexia is derived when many features of dyslexia are taken into account. This not only supports the legitimacy of the factors but also emphasizes the importance of diagnosing dyslexia on the basis of many different tests.

Subtypes of Dyslexia: Factorial Deficits on an Individual Level

We investigated the existence of subtypes of dyslexia based on individual profiles. These profiles were created on the basis of five factorial scores. Because all factor scores were normally distributed within the whole group, deficits of the five factors were determined whereby students whose score fell below the 10th percentile of the group of those without dyslexia were considered as being impaired on that factor, which was the same decision rule applied by Bosse et al. (2007). Table 9 shows for each factor how many students with dyslexia have a deficit. On each factor, 10% of those without dyslexia have a deficit as a result of the decision rule. Table 10 shows the number of deficits for those with dyslexia, those without dyslexia, and not-identified students. A deficit in spelling is the most common of all deficits for those with dyslexia (78%). Furthermore, a majority of those with dyslexia had more than one deficit (75%). In addition, we found that about half of the group of not-identified students had more than one deficit (53%), whereas a very small minority had no deficit (5%). In the study by Bosse et al. (2007), subgroups of those with dyslexia could easily be determined, because they found only two factors. Thus, they found four different groups of those with dyslexia: with either one of the two deficits, with two deficits, or with no deficit at all. In the same way, we tried to categorize all possible profiles of factorial deficits, however, without finding any meaningful categorization of combinations. In our sample, the number of possible combinations of deficits was too large to distinguish meaningful and interpretable subgroups.

Relations With Intelligence: Dyslexia as a Multicognitive Deficit

To evaluate the relation between general intelligence and dyslexia-related abilities, we investigated correlations between factors of dyslexia and factors of intelligence. First, we conducted a PCA on seven measures of intelligence: the

Table 11. Rotated Components Matrix: Three Factors Explaining 65% of the Variance in Seven Measurements of Intelligence (*N* = 446).

	Factor 1	Factor 2	Factor 3
Test of intelligence (sum score)	Nonverbal intelligence	Speed of (numeric) processing	Vocabulary
Variance explained (%)	35.8	15.6	13.2
Raven's Progressive Matrices	**0.70**	0.23	−0.07
Conclusions	**0.59**	0.41	0.18
Hidden pictures	**0.78**	−0.06	0.15
Numeric progressions	0.11	**0.83**	0.07
Speed of calculation	0.14	**0.83**	0.06
Verbal analogies	0.47	0.15	0.53
Vocabulary	0.01	0.06	**0.92**

Note. Extraction method: principal components analysis. Rotation method: Varimax with Kaiser normalization. Rotation converged in five iterations. Bold text indicates high factor loadings.

Table 12. Differences Between Those With and Without Dyslexia on Factors of Intelligence and School Grades.

	With dyslexia (*n* = 58)			Without dyslexia (*n* = 324)						Not identified (*n* = 38)		
Measurement of intelligence	*n*	*M*	*SD*	*n*	*M*	*SD*	*T*	*p*	Effect size	*n*	*M*	*SD*
Factors of intelligence												
Nonverbal intelligence	58	−0.35	0.96	324	0.08	0.99	3.11	.002	0.44	35	−0.18	1.00
Speed of (numeric) processing	58	−0.28	0.77	324	0.06	1.05	2.39	.017	0.37	35	−0.10	0.74
Vocabulary	58	−0.62	0.85	324	0.12	0.98	5.41	<.001	0.81	35	−0.11	1.08
School grades												
School grade Dutch	53	6.48	0.54	291	6.86	0.79	3.32	.001	0.57	32	6.24	1.06
School grade English	53	6.44	1.19	287	6.93	1.13	2.86	.005	0.42	32	6.55	1.25
School grade other languages	55	6.46	0.60	297	6.99	0.65	5.65	<.001	0.85	31	6.69	0.66
School grade mathematics	53	6.50	0.75	299	6.51	0.70	0.09	.929	0.01	32	6.34	1.31
School grade remaining courses	57	6.85	0.55	301	6.92	0.60	0.89	.376	0.12	33	6.63	1.41

six cognitive tests based on Guilford's structure of intellect model and Raven's *Advanced Progressive Matrices Set 2*. The rotated components matrix is shown in Table 11. We found two factors with eigenvalues greater than 1. Interpretation of the scree plot revealed that it is justified to incorporate a third latent variable in the analysis because its eigenvalue was just less than 1 (0.92) and much higher than the next eigenvalue (0.70). We distinguished three factors: nonverbal intelligence, speed of (numeric) processing, and vocabulary, together explaining 65% of the variance. Table 12 shows that those with dyslexia had lower factor scores than those without dyslexia on these factors of dyslexia. The sample sizes are a bit smaller because a few students had no data for intelligence measures. Furthermore, an analysis of group differences of school grades (acquired in our previous study) showed that those with dyslexia had lower scores than those without dyslexia on school grades Dutch, English, and other languages, but not on school grades for mathematics and remaining courses. Effect sizes (Cohen's *d*) were calculated by dividing the differences between the means by the mean of the standard deviations. Large effect sizes were found only for the vocabulary and school grade other languages factors. We should note that most standard deviations are slightly lower for the group of those with dyslexia as compared to those without dyslexia. In addition, the results of the group of not-identified students are presented.

Correlations between severity of dyslexia, factors of dyslexia, and factors of intelligence are shown in Table 13 (with dyslexia) and Table 14 (without dyslexia). We found several remarkable correlations. First, severity of dyslexia correlated with spelling (.41) only in the group of those without dyslexia. Second, in the group of those with dyslexia, the spelling factor correlated negatively with the other factors of dyslexia, of which two were significant: phonology (.31) and whole-word processing/complexity (0.42). In the group of those without dyslexia these correlations were lower or not significant. Third, in the group of those without dyslexia, various low but significant

Table 13. Correlations (Pearson) Between Severity of Dyslexia, Factors of Dyslexia, and Factors of Intelligence.

Cognitive measurement	1	2	3	4	5	6	7	8	9
1. Nonverbal intelligence	1								
2. Speed of (numeric) processing	.169	1							
3. Vocabulary	−.210	.035	1						
4. Severity of dyslexia	−.168	.122	.155	1					
5. Spelling	−.224	−.116	.053	.118	1				
6. Phonology	.018	.034	.160	.127	−.314*	1			
7. Short-term memory	.180	−.040	−.083	.176	−.245	−.044	1		
8. Confusion	.122	.056	−.102	.085	−.206	−.008	−.222	1	
9. Exchange/complexity	.166	.112	.213	.029	−.419**	.058	−.020	−.136	1

Note. Group of those with dyslexia (n = 58). Severity of dyslexia ~ low score.
*Correlation is significant at the .05 level (2-tailed). **Correlation is significant at the .01 level (2-tailed).

Table 14. Correlations (Pearson) Between Severity of Dyslexia, Factors of Dyslexia, and Factors of Intelligence.

Cognitive measurement	1	2	3	4	5	6	7	8	9
1. Nonverbal intelligence	1								
2. Speed of (numeric) processing	−.058	1							
3. Vocabulary	−.039	−.047	1						
4. Severity of dyslexia	.030	.048	.188*	1					
5. Spelling	−.120*	.106	.086	.414**	1				
6. Phonology	−.065	.033	.103	.059	−.084	1			
7. Short-term memory	.117*	.115*	.057	.062	−.200**	−.073	1		
8. Confusion	.118*	−.094	.111*	.070	−.069	−.009	.026	1	
9. Exchange/complexity	.147**	.068	.143**	.181**	−.077	−.091	−.046	−.012	1

Note. Group of those without dyslexia (n = 324). Severity of dyslexia ~ low score.
*Correlation is significant at the .05 level (2-tailed). **Correlation is significant at the .01 level (2-tailed).

correlations were found between factors of dyslexia and factors of intelligence, whereas no significant correlations were found in the group of those with dyslexia.

Discussion

Overview of Main Results

With PCA and a large sample of young psychology students, we found five factors of dyslexia that together explained 60% of the variance in a large battery of specific language tests and language related questions. We named these factors as follows: spelling, phonology, short-term memory, rhyme/confusion, and whole-word processing/complexity. Strong support for the legitimacy of these factors was provided by three analyses. First, five factors from two data sets (tests and questions) loaded on five common latent variables. In a confirmatory analysis we tested a fit of the MTMM model and found a solution with an RMSEA of .03. Second, those with dyslexia had significantly lower factor scores and higher standard deviations than those without dyslexia. Third, prediction analyses showed that all factors contributed to the classification of those with and without dyslexia (with DA 92% correctly classified and with LRA 95% correctly classified).

Regarding the existence of subtypes of dyslexia, we found that 78% of those with dyslexia had a deficit in spelling and that 75% had more than one deficit. However, we could not distinguish any meaningful categorization of combinations of deficits. In addition, we found that about half of the not-identified students had more than one deficit (53%), whereas a very small minority had no deficit (5%).

Furthermore, we investigated relations between factors of dyslexia, severity of dyslexia, factors of intelligence (nonverbal intelligence, speed of [numeric] processing, vocabulary), and school grades. The main findings were that the spelling factor correlated negatively with the other factors of dyslexia only in the group of those with dyslexia and that severity of dyslexia correlated positively with spelling (meaning that high ability in language correlates with high ability in spelling) only in the group of those without dyslexia. Low correlations between factors of dyslexia and factors of intelligence were found in the group of those without dyslexia but not in the group of those with dyslexia. This seems to contradict the finding that those with dyslexia had significantly lower scores than those without dyslexia on all factors of intelligence. However, as expected, those with dyslexia had lower school grades in language courses, but not in mathematics and other courses.

General Evaluation of Results

The main question in this study was how to relate subtypes of dyslexia to the overwhelming quantity of symptoms and theories that have been described in more than 20 years of research. Ramus and Ahissar (2012) concluded that two subtypes of dyslexia can be distinguished in the literature—a majority subtype characterized by a phonological deficit and one or several minority subtypes characterized by a visual deficit—whereas additional subtypes of phonological and visual dyslexia might emerge from the consideration of underlying etiologies. Furthermore, support has been found for a multiple cognitive deficit model as proposed by Pennington (2006) in three studies (Bosse et al., 2007; Di Filippo & Zoccolotti, 2012; Menghini et al., 2010) in which various cognitive abilities were related to reading difficulties of those with dyslexia. Le Jan et al. (2011) found that dyslexia and nondyslexia can be identified with cognitive abilities without making use of reading or spelling assessments. The importance of the present study is that five features related to dyslexia could be extracted from a very large battery of tests and self-report questions that included both language abilities and general cognitive abilities related to dyslexia. This implied that the statistical approach chosen in this study was successful, which may encourage further exploration of accompanying features of dyslexia. Based on these five underlying features of dyslexia, we could not distinguish subtypes of dyslexia. However, future research with a similar approach may clarify the issue of subtypes and the possible existence of more features underlying dyslexia.

The main conclusion from the results in this study is that a multiple cognitive model provides a better explanation of dyslexia than the distinction between subtypes. However, the interpretations of the results of this study with regard to a multiple cognitive view of dyslexia are complex. For instance, we found that a majority of those with dyslexia were characterized by various combinations of deficits, but also that a majority of those with dyslexia were characterized by a spelling deficit. This may be surprising in a student sample. On the other hand, spelling deficits of those with dyslexia are known to persist into adulthood, even after years of remedial teaching. Furthermore, we should emphasize that more cognitive abilities may be involved in dyslexia than were found in the present study. For instance, due to limited testing time we were not able to assess various other abilities such as motor abilities and visuoattentional abilities, although these abilities may have been involved implicitly in the tests that were conducted in this study. Nevertheless, this is the first study that extracted features of dyslexia independently from reading assessment and without making theoretical assumptions beforehand.

Although we did not find subtypes of dyslexia, this may be explained by the fact that the sample was too small in relation to the number of possible combinations of factorial deficits. Alternatively, it is possible that subtypes of dyslexia do not exist, just various combinations of various specific deficits, whereas the underlying nature of and relations between these deficits remain unclear. That some deficits (e.g., phonological) are generally reported more often than other deficits may be explained by selection bias in some studies, or by the fact that unknown deficits were not investigated or were interpreted as other deficits. More support for the view that distinct subtypes of dyslexia do not exist is given by the remarkable finding that in the group of those with dyslexia the most common factor, spelling, did not correlate with severity of dyslexia, whereas it correlated negatively with the other factors of dyslexia. Apparently, a combination of factors is a better predictor of severity in dyslexia than the most common deficit on its own, which was supported by the prediction analyses. Of importance here is that in the present study—in contrast to many similar studies—no participants were excluded, resulting in a small group of students who could not be identified as with or without dyslexia. Half of them were characterized by more than one deficit and most of the rest by one deficit. Maybe a group of people exists that cannot be identified as with or without dyslexia merely as a result of the fact that dyslexia might exhibit itself in only one deficit while compensating for other deficits.

In relation to the finding of more factors than in previous studies, we should emphasize that this study was different regarding three important methodological features: We used a large sample that consisted of well-educated students, the sample was acquired differently than in most other studies, and we conducted exploratory factor analyses not only on tests but also on many specific self-report questions. The finding of a relatively large number of factors probably resulted not only from using many tests and a large sample, but also from the way those with dyslexia were selected. Those with dyslexia in the study by Bosse et al. (2007) were recruited from education authorities and dyslexia centers. However, no specific details were reported regarding how dyslexia was assessed, apart from the fact that all of those with dyslexia were extremely delayed readers. The advantage of the way those with dyslexia were selected for the present study was that two methods were applied: a selection method based on biographical information and a selection method based on prediction analyses without having any preference toward different theories of dyslexia. This resulted in the identification of those with dyslexia of varying severity and based on many symptoms. In the sample of Bosse et al., highly intelligent children with dyslexia may have been excluded and children without dyslexia with delayed reading may have falsely been included, which could explain that 23% of the children with dyslexia were found to have no deficit at all. In contrast, we found no children with dyslexia without a selective deficit (25% had only one deficit). Even in the group of not-identified students, we found only a very small group (5%) of students without a deficit.

Evaluation of Separate Factors

The most common deficit of those with dyslexia in this study is a spelling deficit. Apparently, spelling difficulties are challenging to overcome even in a sample of highly educated students and even after extensive training at school, which is common practice today for those with dyslexia in Dutch schools. Although there is nothing revolutionary about impaired spelling being the most general feature of dyslexia, this factor is difficult to relate to previous findings. Bosse et al. found a visual attention factor that was a strong independent predictor of reading speed, even after controlling for single letter identification skills. Also Di Filippo and Zoccolotti (2012) did not find a factor that could clearly be related to spelling abilities. Thus, finding a spelling deficit is not new, but finding this deficit existing independently from phonological and other abilities is new according to our knowledge.

Probably the mostly investigated symptom of dyslexia for decades is the phonological deficit. However, the exact nature of this deficit is still a topic for debate. Some researchers consider a phonological deficit as a core deficit of dyslexia that originates in the phonological lexicon (e.g., Snowling & Hulme, 2005). In contrast, others have found support for a phonological processing deficit that results from impaired retrieval from the lexicon, with the phonological representations in this lexicon itself being unimpaired (Blomert, Mitterer, & Paffen, 2004; Ramus & Szenkovits, 2008). This view was confirmed in a recent functional magnetic resonance imaging study (Boets et al., 2013) that showed that adults with dyslexia have intact but less accessible neural representations of speech sounds. Although the results of the present study cannot support either of these views, clearly phonology is a symptom of dyslexia.

A third unsurprising factor in this study is short-term memory (STM), which is a well-known and generally accepted symptom of dyslexia (e.g., De Jong, 1998). Working memory is generally understood as a dynamic mechanism assumed to consist of four parts: the central executive, a visuospatial sketch pad, a phonological store, and an episodic buffer (Baddeley, 1986, 2000, 2002). The related STM construct is held to describe systems solely involved in temporary storage of information (e.g., Baddeley, 1990, 2003). However, because we used the digit span tasks in our study, it was not possible to tell whether we were dealing with a deficit in storage or with a deficit of memory-related executive functions.

Two factors in this study have not been described before in the literature to our knowledge. One was rhyme/confusion, which represented the confusion factor in specific language-related questions and the Dutch–English rhyme words test. The other was whole-word processing/complexity, which represented the complexity factor in specific language-related questions and the spoonerisms and letter order tests. First, we considered it to be surprising that these last two tests did not load on the confusion factor. However, because support for complex cognitive etiologies in dyslexia has become stronger in recent years, it should not surprise us that we found factors that we cannot explain based on the knowledge we have so far. Apparently, there are two processing factors that independently contribute to difficulties of those with dyslexia.

Dyslexia as characterized by processing deficits is in line with the finding of phonological processing difficulties and with the finding that the visual attention factor of Bosse et al. was a predictor of reading speed. Also, it is consistent with the finding of a processing factor in the study of Di Filippo and Zoccolotti (2012) regarding their pictorial naming factor. As mentioned in the introduction, they proposed that naming slowness refers to the ability to retrieve name codes from the semantic lexicon and is not specifically related to activation of the orthographic lexicon. Although it is purely speculative, we suggest that factors of naming slowness or impaired visual attention may be related or even the same as the two factors in this study. For the Dutch–English rhyme words test, both words must be named silently to determine whether these words sound the same or not. However, the underlying etiology of this factor remains unclear because any causal direction is unclear: Confusion, such as exchanging letters, might influence naming speed, or impaired naming speed might result in confusion.

Regarding the whole-word processing/complexity factor, we should mention two reading models that have been of special interest in relation to dyslexia. The dual route model of reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; De Groot et al., 1994; Ziegler et al., 2008) and the multitrace memory model of polysyllabic word reading (Ans, Carbonnel, & Valdois, 1998) both postulate that there are two different strategies in reading. The analytical strategy is used by starting readers and for reading difficult new words: Words are analyzed letter by letter and/or phoneme by phoneme. The global strategy, or direct route, is mainly used for words that are well known: the word is recognized as a whole. If those with dyslexia make more use of the analytical route than normal readers, this can explain a marked word length effect found in those with dyslexia for both words and nonwords, suggesting the use of a letter-by-letter strategy (Marinus & De Jong, 2010).

Furthermore, we should mention that it has been emphasized that deficits of visual attention span especially prevent putting attention to the whole word (Bosse et al., 2007, 2009). Thus, when words become longer and more complicated, those with dyslexia may still persist in a letter-by-letter strategy whereas those without dyslexia maintain a global strategy. Therefore, the whole-word processing and complexity factors represented the same latent variable in this study.

In summary, it is important to realize that it is not essential here to be able to explain all factors theoretically. The main finding is that, clearly, five psychometric factors of dyslexia could be distinguished that all seem to be related to some kind of general cognitive information processing. Support for each factor can be found in the literature. However, underlying etiologies remain unclear as long as no evidence has been found for causal relations between these factors.

Dyslexia, Intelligence, and Coping Strategies

In general, a disadvantage of using a student sample is that conclusions cannot be generalized to a general population. However, the advantage of using a student sample in studies of dyslexia is that low performances on tests cannot alternatively be explained by low intelligence, something that is a complicating factor in diagnosing dyslexia in young children. Thus, student samples complicate evaluations of conclusions about the relation among intelligence, schooling, coping strategies, and dyslexia.

In the present study, we found support for dyslexia as a multiple cognitive deficit, but we were not able to distinguish subtypes on the basis of various combinations of deficits. Here, we emphasize that this also might result from differences in coping strategies, especially in a sample of students. Students are smart and well educated and can therefore be expected to have developed advanced coping strategies. However, these coping strategies might differ individually. This is supported by the finding that the variability of the factor scores was higher in the group with dyslexia than in the group without dyslexia, in contrast to the variability of the factor scores of intelligence. Higher variability for those with dyslexia is a general finding in the literature, but here the contrast with intelligence measures is striking. One possible explanation we can proffer is that, within the group of those with dyslexia, separate symptoms are robust on an individual level. During childhood those with dyslexia may try to compensate for dyslexia-related abilities that are not very impaired, whereas other dyslexia-related abilities remain impaired. In other words, what is weak stays weak and what is not so weak becomes stronger. This might enhance negative correlations between, for instance, spelling and other factors of dyslexia, and thus the existence of those with dyslexia characterized by various combinations of deficits. This view supports the idea that causal subtypes do not exist, but merely symptoms that depend on individually different coping strategies.

The discussion about underlying etiologies versus coping strategies in dyslexia is also relevant for the findings in this study regarding intelligence measures. Those with dyslexia had poorer performances on all three factors of intelligence (without showing higher variabilities), however not on school grades mathematics and other courses that are unrelated to language. Seemingly inconsistent with this is that in the group of those with dyslexia no correlations were found between factors of dyslexia and factors of intelligence, whereas there were some weak correlations in the group of those without dyslexia. We should be cautious drawing conclusions; students with dyslexia having relatively low scores on measures of intelligence cannot be generalized to a general population, because the average intelligence of students is much higher than that of the general population. Maybe at high levels of performance standard intelligence measures are not suitable for assessing differences between those with and without dyslexia. We found four arguments in favor of this explanation. First, it is remarkable that school grades of mathematics and language-unrelated courses did not differ between the groups. Second, standard intelligence measures may be influenced by dyslexia, also when performing on high levels of intelligence. Although intelligence measures are supposed to be unrelated to dyslexia, many intelligence tests partly depend on language skills, such as vocabulary, verbal analogies, and conclusions. Third, various coping strategies might influence intelligence measures. The finding of unknown factors in this study also means that we should account for unknown and maybe unconsciously driven coping strategies starting at very early ages during childhood that might affect intelligence measures as well. Fourth, unknown factors as found in this study might also directly affect nonverbal intelligence measures to some extent. For instance, in studies of dyslexia, groups are usually matched on intelligence often using *Raven's Progressive Matrices*. However, poorer performances by those with dyslexia on this kind of test are often overlooked because group differences did not reach significance in studies using small samples. Assuming that dyslexia and intelligence are both characterized by multiple cognitive abilities, it would be strange to not have mutual influence.

Conclusion

In summary, we propose that dyslexia is characterized by various known and unknown cognitive deficits, whereas it remains unclear whether these deficits arise from different etiologies or from different coping strategies. In future studies, it should be investigated whether the same features of dyslexia can be found in samples of children and general adult populations and with different tests. For future research, we propose that the etiologies of factors of dyslexia should be investigated in relation to etiologies of general intelligence. We conclude that as we dig deeper and deeper, we may start to see something that is much more complicated than we could ever have imagined. Maybe we should leave the classification of dyslexia as a disorder and instead accept dyslexia as an alternative way of information processing that has evolved over thousands of years without being noticed.

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